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OIL AND GAS DEVELOPMENTS
IN THE
APPALACHIAN BASIN PAST AND PRESENT

BY

CHAS. R. FETTKE

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OIL AND GAS DEVELOPMENTS IN THE APPALACHIAN BASIN

Past and Present

By
CHAS. R. FETTKE *

The Appalachian basin includes the ea in which the modern petroleum dustry started. Its oil and gas fields ive had the longest production hisry of any on the North American ntinent. Their commercial developent dates from the discovery of oil a stray sand of Upper Devonian e at a depth of 69 feet in the Drake Vell along Oil Creek south of Tituslle in northwestern Pennsylvania in ugust 1859. Even prior to that, the esence of oil and gas had been obrved at a number of widely scattered calities in the basin and these subances had been utilized on a small ale for illuminating, lubricating, and edicinal purposes.

efinition and Boundaries of Basin

The Appalachian basin is a broad ymmetrical and complex stuctural ough or synclinorium whose long is trends northeast and southwest, ith the steep limb on the southeast de. On the southeast (Plate 1) it is unded by the closely folded Aplachian Mountains, on the northst by the Adirondack Mountains d the Frontenac arch, on the north the Pre-Cambrian highlands of entral Ontario, on the northwest by e Findlay-Algonquin arch, and on e west by the Cincinnati arch. On e southwest the basin is overlapped the Mesozoic and Cenozoic strata the Gulf Coastal Plain. Many of e rock formations of the basin exnd considerable distances beyond the nits of the present structural trough d their deposition in part was conolled by lineaments outside the undaries of the trough, as outlined ove.

rea Included

As outlined, the Appalachian basin cludes all of New York southwest d west of the Adirondack Mounins; the southern part of southwestn Ontario; northeastern, northntral and western Pennsylvania; e eastern three-fourths of Ohio; a nall area in extreme western Maryland; most of West Virginia; eastern entucky, east of the Blue Grass lowland; a narrow strip along the northwestern margin of southwestern Virginia; that part of Tennessee lying between the Nashville lowland and the Ridge and Valley province; the northwestern Part of Alabama; and the northeastern corner of Mississippi.

The oil and gas fields of the Appalachian basin comprise the Appalachian province. This oil and gas province includes the fields of New York, southwestern Ontario, Pennsylvania, eastern and middle Ohio, West Virginia, eastern Kentucky, several small oil and gas pools in middle Tennessee, and three small gas pools in northwestern Alabama and adjacent Mississippi. Oil and gas production, thus far in Tennessee has been relatively small and the amount of gas recovered from the now abandoned three small gas pools in Alabama and Mississippi almost negligible. A commercial gas pool has recently been developed in western Maryland and one small oil field and several gas fields have been discovered in southwestern Virginia.

The province can be divided into several subprovinces on the basis of the age of the producing formations, as, for example, the Mississippian subprovince of eastern Ohio, southwestern Pennsylvania, western and southern West Virginia, and eastern Kentucky; the Upper Devonian subprovince of western New York, western Pennsylvania and northern West Virginia; and the Albion (Medina) subprovince of western New York, southwestern Ontario and Middle Ohio. However, these subprovinces overlap considerably along their borders.

Past and Present Importance

Beginning in 1859, the annual production in the Appalachian province rose until it reached a peak of 36,295,000 barrels by 1900. This represented 57 per cent of the total production of the United States during that year. At the end of 1900 or during the first 40 years of the petroleum industry's history, 73.5 per cent of the total oil production in the United States had come from the province.

After 1900, production declined until in 1915 it had dropped to a low of 22,860,000 barrels. An [illegible] trend followed the introduction of secondary recovery methods, particularly water flooding in the Bradford field of Pennsylvania, and in 1937 production was up to 33,000,000 barrels. Since then, the trend has been gradually downward.

The annual production for 1951 is estimated at 22,800,000 barrels. This represents only a little over one per cent of the total production of the United States for that year. At the end of 1951, the total production of the Appalachian province accounted for only 5.2 per cent of the total production of the United States in contrast to 73.5 per cent at the end of 1900. This emphasizes the rapidity with which the American oil industry has grown and the magnitude that it has attained since the beginning of the present century.

The Appalachian basin is the home of the famous Pennsylvania Grade crude oil. This oil is noted for both the quality and quantity of its lubricating fraction. It is of relatively uniform quality although produced from many sands ranging in geologic age from Pennsylvanian to Ordovician. In 1949, 11.1 per cent of the lubricants produced in the United States were derived from Pennsylvania Grade crude oil although the production of this crude amounted to only 1.1 per cent of the total produced in the United States during that year.

The Pennsylvania Grade crude oil region includes the fields of New York, Pennsylvania and West Virginia and most of those in southeastern Ohio. The small production in southwestern Virginia is also Pennsylvania Grade.

In 1951, 85.6 p[illegible] palachian produc[illegible] Pennsylvania G[illegible] this, 49.5 pe[illegible] Bradford [illegible]

The Appalachian province in 1948 accounted for 8.4 per cent of the total natural gas produced in the United States during that year, but this relative position is rapidly declining due to the tremendous expansion of natural gas production in the western United States.

* Professor of Geology, Carnegie Institute of chnology, and Co-operating Geologist, Pennsylnia Bureau, Topographic and Geologic Survey.

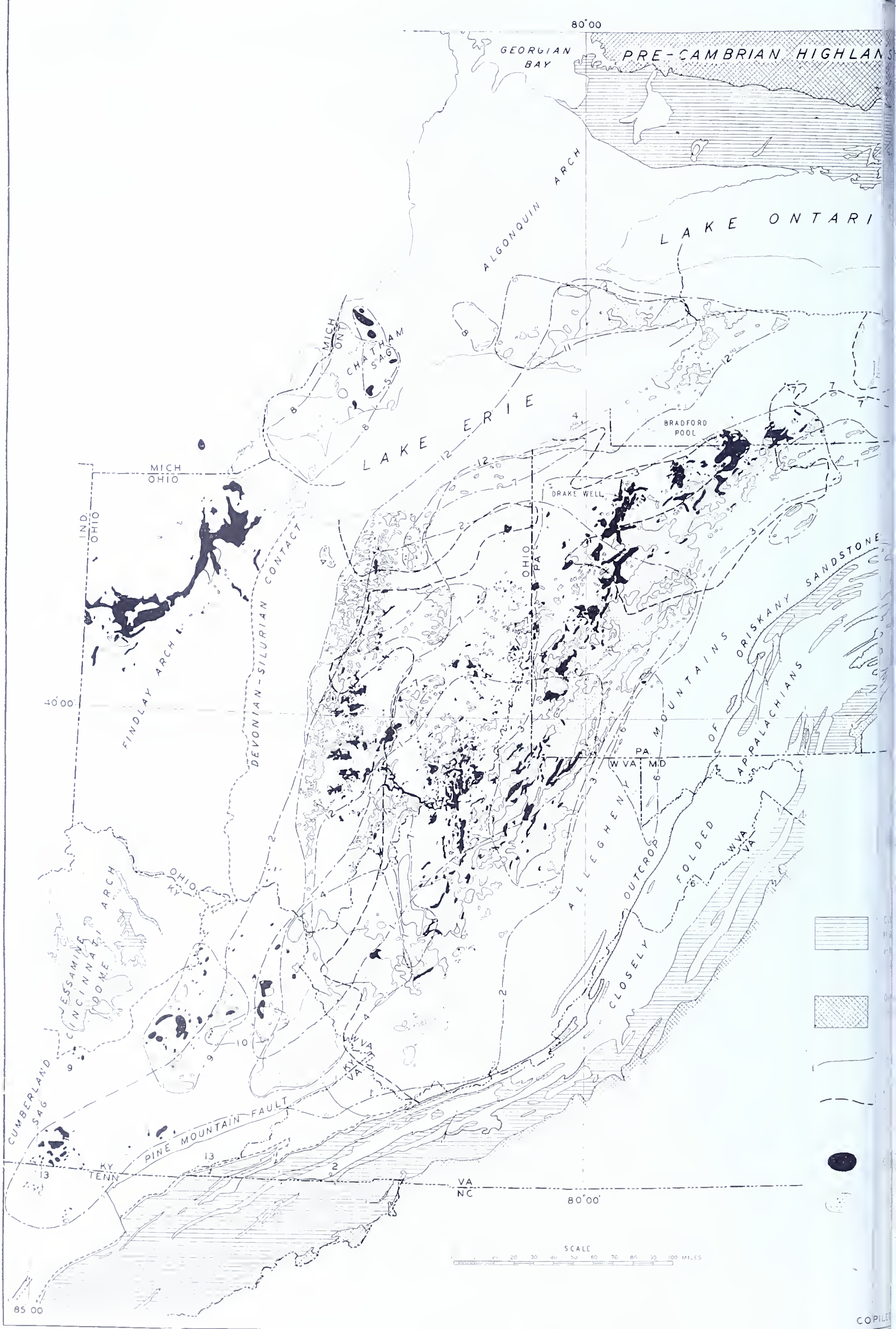
80°00
GEORGIAN BAY
PRE-CAMBRIAN HIGHLAN
LAKE ONTARI
ALGONQUIN ARCH
MICH ONT
CHATHAM SAG
LAKE ERIE
BRADFORD POOL
MICH OHIO
IND. OHIO
DRAKE WELL
OHIO PA
DEVONIAN-SILURIAN CONTACT
FINDLAY ARCH
ORISKANY SANDSTONE
40°00
MOUNTAINS
OF
APPALACHIANS
PA.
W VA
MD
ALLEGHENY
OUTCROP
FOLDED
W VA
VA
CLOSELY
OHIO KY
JESSAMINE DOME
CINCINNATI ARCH
CUMBERLAND SAG
W VA
KY VA
PINE MOUNTAIN FAULT
KY TENN
VA NC
80°00'
SCALE
85 00
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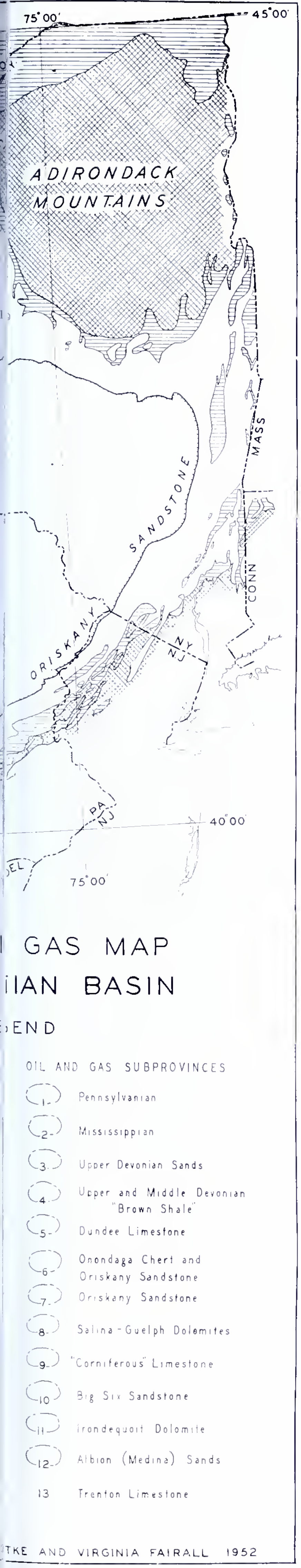
PLATE I



Geology

The boundaries of the Appalachian basin coincide roughly with the boundaries of the Appalachian Plateau physiographic province. The basin extends beyond the plateau along its northwestern, western and southwestern margins. The western edge of the maturely dissected plateau in central Ohio and northern Kentucky is 1200 to 1300 feet high and has a local relief of from 200 to 300 feet. Eastward the surface rises gradually to about 1600 feet in Pennsylvania at the western edge of the Allegheny Mountains which form the high eastern margin of the plateau. The tops of the mountains have elevations of from 2900 to 3100 feet above sea-level. Toward the north, the plateau rises to about 2100 feet along the Pennsylvania-New York boundary and in middle West Virginia to elevations of 3500 to 4000 feet and even higher. With rise in elevation, the relief increases and the topography becomes more rugged. The higher parts, to a large extent, are densely wooded and are traversed by winding streams intrenched in mountain gorges 1000 or more feet deep.

All of the systems of the Paleozoic Era are represented in the Appalachian basin. The central part of the basin is floored with beds of Permian age which are surrounded by outcrops of Pennsylvanian rocks. The latter cap the major part of the Appalachian plateau south of the New York-Pennsylvania boundary. Mississippian, Devonian, Silurian and older strata crop out in sequence along the western, northern and southeastern margins. At the southwestern end the Paleozoic strata pass underneath the Cretaceous and younger sediments of the Gulf Coastal plain.

Along the Allegheny Front, the eastern edge of the Appalachian plateau, and east of it in the closely folded Applalachian Mountains of central Pennsylvania, the exposed Upper Cambrian to Mississippian section inclusive has a thickness of over 21,000 feet. Due to the thinning of many of the formations westward and the cutting out of others by unconformities the corresponding interval in central Ohio includes less than 5000 feet of strata. In the southwest corner of Pennsylvania, the Pennsylvanian System has a thickness of 1500 feet and the Permian, 1100 feet.

Stratigraphy

The general geologic section in Table 1 shows the succession and nature of the formations underlying the northern part of the Appalachian basin. The stratigraphic positions of the more important oil- and gas-bearing sands, as developed in Pennsylvania, are indicated. A columnar section of the strata penetrated by the deepest stratigraphic test to date in western Pennsylvania is shown graphically in Figure 1. The part of the column which contains the Upper Devonian is shown in more detail for the northern, middle, and southwestern districts of western Pennsylvania in Figure 2.

Producing Horizons

The reservoir rocks in which oil and gas in commercial quantities have been found in the Appalachian basin range in age from Pennsylvanian to Ordovician.

Sandstones in the Pennsylvanian System have yielded substantial volumes of gas and some oil in southeastern Ohio, western Pennsylvania, northwestern West Virginia and eastern Kentucky.

Mississippian sandstones, and to a lesser extent, limestones have been important sources of both oil and gas in eastern Ohio, western Pennsylvania, western West Virginia and eastern Kentucky. The Berea sandstone, near the base of the Mississippian System, has been a great producer of oil.

Oil production in New York has been confined to sandstones in the Upper Devonian Series. The same sandstones have also yielded natural gas. The major part of the oil production in Pennsylvania and a considerable part of that in West Virginia has also come from Upper Devonian sandstones; likewise, large volumes of gas. Upper and Middle Devonian black shales in eastern Kentucky and southwestern West Virginia have been a great source of gas. Most of Ontario's oil production has come from a Middle Devonian limestone formerly correlated with the Onondaga limestone of New York but now thought to be the equivalent of the Dundee limestone of Michigan. Substantial volumes of gas have been encountered in fractured Onondaga chert and Oriskany sandstone of Middle and Lower Devonian age, respectively, in southwestern Pennsylvania, western Maryland and northeastern West Virginia. The Oriskany sandstone of the Lower Devonian has been the source of large volumes of gas in south-central New York, north-central Pennsylvania and southwestern West Virginia. Gas and some oil have also been obtained from it in east-central Ohio.

Salina and Guelph dolomites of Upper and Middle Silurian age, respectively, have yielded considerable oil and have been important producers of gas in southwestern Ontario. Gas has been obtained locally from the

Lockport dolomite of the Middle Silurian in northeastern Ohio east of Cleveland. The so-called "Corniferous" limestone of eastern Kentucky, a major producer of petroleum, consists of two dolomites, the Peebles and Lilley, in descending order, locally comprising the Lockport group of the Middle Silurian. The Big Six sandstone, a source of gas in eastern Kentucky, probably correlates with the Keefer sandstone member of the Clinton group of the Middle Silurian. The Irondequoit dolomite near the base of the Clinton group contains gas locally in southwestern Ontario. The sandstones of the Albion (Medina) Series of the Lower Silurian have been an outstanding source of gas in weste
New York, southwestern Ontario a
central Ohio. In central Ohio, wh
these sands are commonly call
"Clinton," some oil has also been
tained from them.

To date, rocks older than Siluri
have contributed only minor quan
ties of oil and gas to the producti
of the Appalachian Basin. The Tr
ton production in northwestern Oh
and adjacent Indiana belongs to t
Cincinnati Arch province, not the A
palachian. A little gas for local u
has been obtained from the Trent
limestone of the Middle Ordovici
on the southwest flank of the Adir
dack Mountains in New York. Tr
ton, Black River and Stones Riv
limestones of the Middle Ordovici
have provided a little oil and gas
south-central Kentucky and nort
central Tennessee. Gas in commerc
volumes has recently been encounter
in eastern Kentucky in a sand th
occurs a short distance above the u
conformity at the top of the Low
Ordovician Knox dolomite. The sma
oil field in southwestern Virginia pr
duces from fractured Trenton lim
stone. A little oil and gas have be
obtained from the Knox dolomite
Lower Ordovician age in central Te
nessee and shows of oil have been e
countered in this dolomite at a numb
of places in eastern Kentucky.

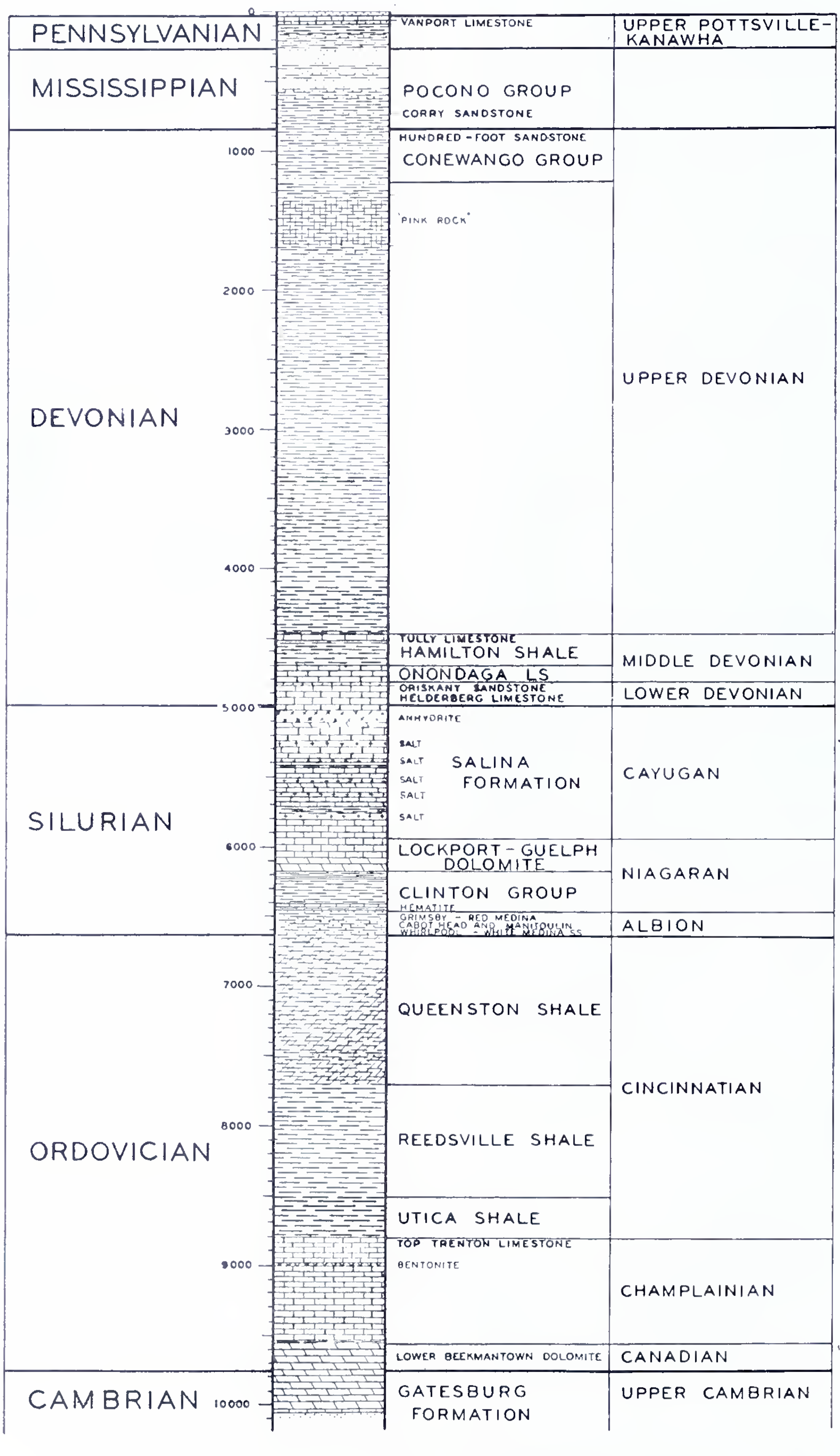
A small amount of oil has been o
tained from sandy zones in what t
writer believes to be the Trempeles
formation of the Upper Cambrian
four localities in Ohio. (Fettke, 194
pp. 1491-1492)

Unconformities

Three unconformities in the Pal
ozoic section of the Appalachian bas
are noteworthy. In descending orde
they occur between the Pennsylvania
and the Mississippian Systems, b
tween the Devonian and the Siluria
Systems, and between the Middle an
Lower Ordovician Series.

In northwestern Pennsylvania, th
Pottsville sandstone of the Pennsy
vanian System rests upon the Knap
formation, the basal formation of th
Mississippian System, whereas
southwestern Pennsylvania the Pott
ville overlies the Mauch Chunk shal
the youngest formation of the Missi
sippian. Only the youngest membe
of the Pottsville Series are present
western Pennsylvania and the enti
thickness of the series is only 220 fee
In southern West Virginia, the Pott
ville attains a thickness of 3850 fe
and in northern Alabama, 9000 fee

On the southeastern edge of th
Appalachian Basin, the Coeymar
limestone at the base of the Lowe



COLUMNAR SECTION
WESTERN PENNSYLVANIA
OBTAINED IN JESSIE G HOCKENBERRY WELL NO I
MANUFACTURERS LIGHT & HEAT COMPANY
MERCER TOWNSHIP, BUTLER COUNTY, PA

FIGURE I

vonian rests upon the Keyser limene at the top of the Upper Silurian. western New York in the vicinity Buffalo, the Onondaga limestone the Middle Devonian is in contact h the Akron dolomite of the Upper urian. All of the Lower Devonian l some earliest Middle Devonian l some latest Silurian are absent. Highland County in south-central io, the Olentangy shale of latest ddle Devonian age rests upon the eenfield dolomite of earliest Upper urian age. The unconformity be- een the Devonian and Silurian is ticularly striking in central Ken- ky where, in the area of the out- p of this interval, there is an over- of Middle Devonian (Hamilton) estone onto Middle Silurian ockport) to Upper Ordovician ichmond and Maysville) strata vard the Cincinnati Arch. The oc- rence of oil and gas in the Irvine- Sinking and other "Corniferous" ds in eastern Kentucky appears to e been controlled by the presence the unconformity. (McFarlan, 38, p. 1451.)

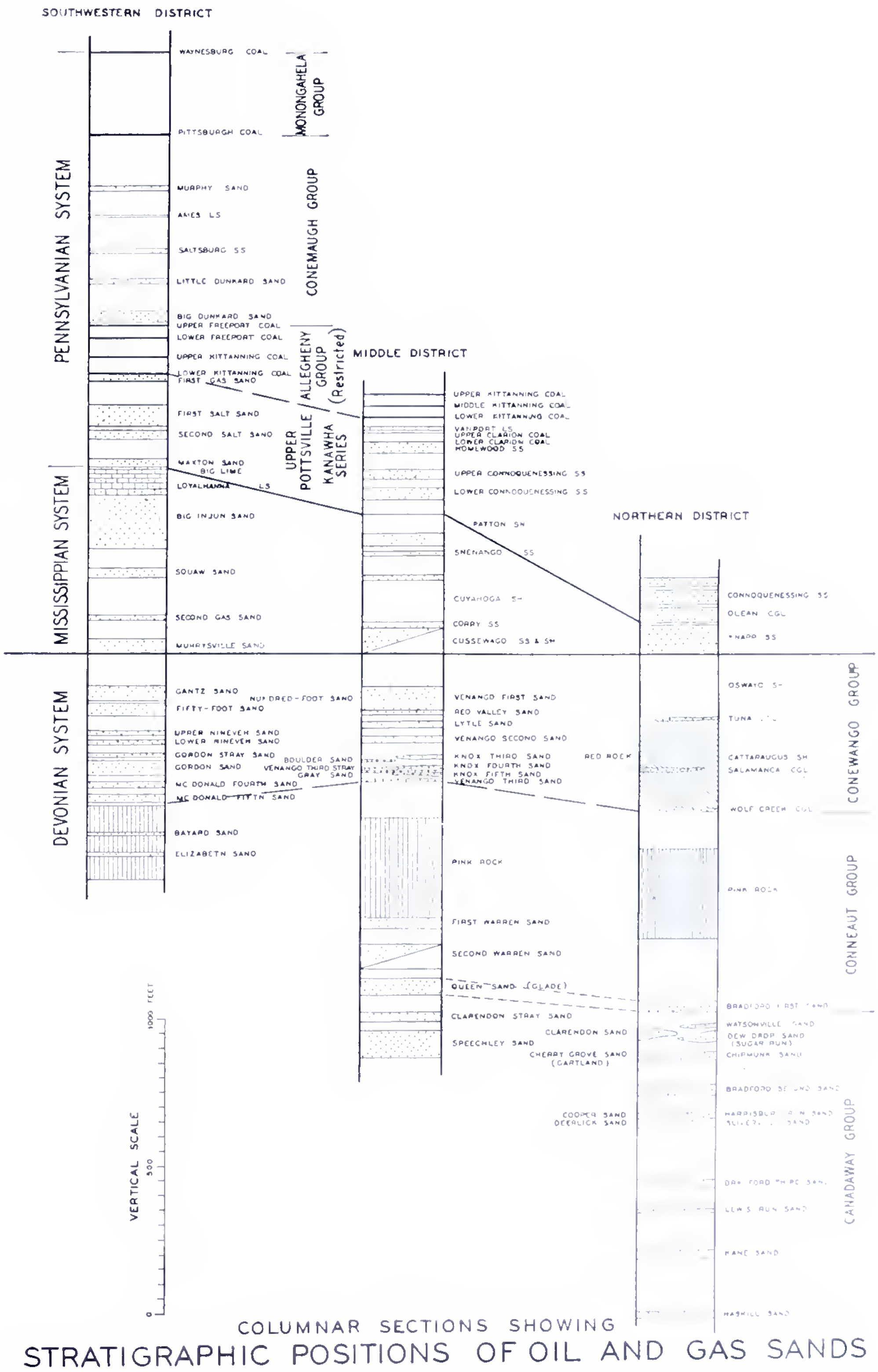
The most prominent unconformity the Lower Paleozoic section occurs the base of the Middle Ordovician. ere is no sharp lithologic break be- een the Middle Ordovician (Loys- rg) limestone and the Lower Or- vician (Bellefonte) dolomite in tral Pennsylvania. The Loysburg presents earliest Chazy in central nnsylvania and the Bellefonte, lat- Beekmantown. In a deep well in stern Pennsylvania the Middle Or- vician Black River limestone was nd to overlie what is probably a sal Lower Ordovician dolomite. All the Chazy of the Middle Ordo- ian and most of the Beekmantown the Lower Ordovician are missing. out 120 miles east at the south- stern edge of the Appalachian basin central Pennsylvania, this interval represented by approximately 4500 t of strata (Fettke, 1948, p. 1486). north-central Ohio, Black River nestone appears to rest on Upper mbrian dolomites and dolomitic ndstones and siltstones. Chazy and ekmantown strata apparently are sent. Early Lower Ordovician dolo- ites are encountered in wells on the est, south and east. North and rtheast, in southwestern Ontario d northeastern Ohio, the Black iver limestone successively overlaps e beveled edges of older and older pper Cambrian formations until ally it comes to rest on the Pre- ambrian at the northern edge of the ppalachian basin north of Lake On- rio.

Igneous Rocks

Igneous intrusions in the form of peridotite dikes occur at a number of localities in the Appalachian basin. One of these is in the vicinity of Little Falls, New York at the northeastern edge of the basin and another near Syracuse, New York. Others occur in the vicinity of Ithaca in south-central New York; at Dixonville, Indiana County, and Masontown, Fayette County, in western Pennsylvania; and in Elliot County in eastern Kentucky. Inasmuch as the dikes in Kentucky and Pennsylvania cut Pennsylvanian rocks, they are generally considered to be post-Pennsylvanian in age. The Joe Farkas No. 1 well of the Reserve Oil Company, located 6 miles north of Ithaca, New York, encountered one of the mica peridotite dikes in that vicinity at a depth of 4800 to 4838 feet while drilling in the Oswego sandstone of the Upper Ordovician.

Structure

The broad asymmetrical structural trough or synclinorium that constitutes the Appalachian basin is modified by a series of minor folds with axes trending northeast and southwest



COLUMNAR SECTIONS SHOWING
STRATIGRAPHIC POSITIONS OF OIL AND GAS SANDS
OF WESTERN PENNSYLVANIA
FIGURE 2

TABLE 1. GENERAL GEOLOGIC SECTION FOR NORTH-CENTRAL AND WESTERN PENNSYLVANIA

System	*Series*	*Group or Formation*	*Description*	*Approximate Thickness Feet*
PERMIAN	Dunkard	Greene	Predominately shale, in part red, sandy shale and shaly sandstone; a few massive sandstones; several thin coal and fresh-water limestone beds.	1100
		Washington	Shales, sandstones, and thin beds of coal and fresh-water limestone.	
PENNSYLVANIAN		Monongahela	Shale and fresh-water limestone, subordinate sandstone, several workable coal beds, Waynesburg coal at top and Pittsburgh coal at base.	330
		Conemaugh	Shale, in part red, and subordinate sandstone; several thin coal and fresh-water and marine limestone beds. Contains Murphy, Little Dunkard and Big Dunkard sands in descending order in southwestern district.	600
		Allegheny (restricted)	Shale and subordinate sandstone and limestone; several workable coal and fire clay beds. Upper Freeport coal at top and Lower Kittanning at base.	175
	Pottsville		Massive medium- to coarse-grained sandstone and subordinate shale, clay, and limestone. Contains First Gas, First and Second Salt, Maxton sands in southwestern district.	315
Unconformity			An erosional unconformity and bevels successively younger southerly dipping Mississippian strata in going from north to south in western Pennsylvania. In McKean County, Pottsville sandstone rests upon the Knapp formation, the lowest member of the Mississippian system; while in Fayette County, the Pottsville overlies the Mauch Chunk red shale, the highest member.	
MISSISSIPPIAN		Mauch Chunk	Gray and red shale, subordinate fine-grained sandstone.	0–100
		Greenbrier	Consists, in descending order, of limestone, a shale break, and the Loyalhanna sandy limestone.	0–80
		Pocono	Fine to coarse-grained, massive sandstone and shale. Knapp sandstone and shale at base. Contains Big Injun, Squaw, Berea and Murraysville sands in southwestern district.	570–900
DEVONIAN	Upper Devonian	Conewango	Gray shale and subordinate, fine- to coarse-grained light gray sandstone; red shale prominent in lower part in northern district; some purplish-red shale in middle and southwestern districts. Contains the Venango First, Second and Third sands in the middle district, and the Gantz, Fifty-Foot, Upper and Lower Nineveh, Gordon, and McDonald Fourth and Fifth sands in the southwestern district.	3300–6000 from northwe[st] to southeast
		Conneaut	Gray and purplish-gray shale and sandy shale, subordinate sandstone. Contains the Bradford First or Glade sand in the northern district; the Queen sand in the middle district; and the Bayard and Elizabeth sands in the southwestern district.	
		Canadaway	Gray shale and sandy shale, subordinate fine- to coarse-grained light gray sandstone and fine-grained chocolate-brown sandstone. Contains the Clarendon, Cherry Grove, Bradford Second, Cooper, Bradford Third, Kane and Haskill sands in the northern district; the Speechley sand in the middle district; and the Speechley and Bradford sands in the southwestern district.	
		Chemung	Gray shale and sandy shale, subordinate fine-grained sandstone.	
		Portage	Gray shale and sandy shale.	
		Genesee	Dark gray and black shale.	
		Tully	Argillaceous limestone.	0–150
DEVONIAN (Continued)	Middle Devonian	Hamilton	Dark gray and black shale, in part calcareous.	140–1600
		Onondaga	Cherty limestone and chert, subordinate dark silty, shaly and glauconitic beds. Major source of gas in Summit field.	30–290
		Oriskany	*Upper* medium-grained quartz sandstone member (Ridgeley), locally calcareous. Source of gas in north-central Pennsylvania and in South Beaver, Dry Ridge, and Summit fields in southwestern Pennsylvania.	0–110

TABLE 1. GENERAL GEOLOGIC SECTION FOR NORTH-CENTRAL AND WESTERN PENNSYLVANIA

System	Series	Group or Formation	Description	Approximate Thickness Feet
	Lower Devonian		*Lower* silty and cherty limestone member, (Shriver) occasionally sandy.	0–100
		Helderberg	Non-magnesian, in part cherty, and frequently very fossiliferous limestone.	0–350
	Upper Silurian or Cayugan	Cobleskill	Argillaceous magnesian limestone.	25–100
		Salina	Interbedded, dense, argillaceous magnesian limestone, gray shales and clays for the most part either calcareous or dolomitic. Numerous interbedded layers of anhydrite and salt. Small gas production in McCance field.	450–2800
ILURIAN	Middle Silurian or Niagaran	Lockport	Very fine, crystalline, brownish-gray to very dark grayish-brown, relatively pure dolomite. A salt-water zone frequently present. Small gas production in Henderson field.	240–320
		Clinton	Shale, dolomitic shale and subordinate dolomite. Fine-grained light-gray sandstone at base—Thorold.	100–300
ILURIAN (Continued)	Lower Silurian or Albion	Grimsby or Red Medina	Red sandstone and shale. Small gas production in northwestern Pennsylvania.	70–220
		Cabot Head and Manitaulin	Gray shale and subordinate very fine-grained light gray sandstone.	
		Whirlpool or White Medina	Fine-grained light gray sandstone. Small gas production in northwestern Pennsylvania.	
	Upper Ordovician or Cincinnatian	Queenston	Red shale, in part silty and sandy.	850–1200
		Oswego	Very fine-grained gray sandstone.	0–60
		Reedsville	Gray shale.	700–800
		Utica	Black shale.	100–300
RDOVICIAN	Middle Ordovician or Champlain	Trenton and Black River	Limestone, in part argillaceous, and either non-magnesian or only slightly magnesian.	650–750
	Unconformity		Approximately 4500 feet of Lower Ordovician strata present in central Pennsylvania are missing in western Pennsylvania.	
	Lower Ordovician or Canadian	Lower Beekmantown	Fine to medium, crystalline light gray dolomite.	0–190
AMBRIAN	Upper Cambrian	Gatesburg	Fine, crystalline, light brownish-gray dolomite with siliceous oölite zone near middle. Grades into fine, crystalline, sandy dolomite and fine to medium-grained light gray, somewhat dolomitic sandstone in lower part.	350–

ɔproximately parallel with the long xis of the trough. On the southeast eep limb these consist of strong well efined anticlines and synclines, but ɔrthwestward the intensity of folding diminishes so that the folds become ss prominent in the central part of ie basin and disappear in the northest part.

Deep drilling for Oriskany gas has vealed that the folds are much more omplex structurally than had been nticipated from the earlier surface apping. It has been found that exnsive commonly northwest-dipping verse faults intersect and complexly odify the outlines of the more prominent domes along the anticlinal axes the Oriskany horizon. Vertical separations of as much as 850 feet have een encountered at this horizon. Although some of the faults have been cognized on the outcrop, no displacement of this magnitude has been observed.

The axis through the lowest part of the basin mapped on the Pittsburgh coal at the base of the Monongahela group of the Pennsylvanian System trends in a general northeast-southwest direction. It passes through Pittsburgh, Pennsylvania and a point about 10 miles south of Huntington, West Virginia. The deepest part of the basin at this horizon occurs in the southwest corner of Pennsylvania where the Pittsburgh coal has an elevation of only 100 feet above sea-level. The top of the Oriskany sandstone of the Lower Devonian here is 6500 feet below sea-level. Due to the southeastward thickening of the strata between the Pittsburgh coal and the Oriskany sandstone, particularly the strata belonging to the Upper Devonian Series, the deepest part of the trough when mapped on the top of the Oriskany sandstone lies only a short distance northwest of the southeast edge of the basin. At the bottom of the Casselman-Berlin syncline, the prominent syncline west of the Deer Park anticline which brings the Oriskany sandstone to the surface on the Schellsburg dome in south-central Pennsylvania, the projected elevation on the Pittsburgh coal is 2100 feet above sea-level and on the top of the Oriskany sandstone, 8100 feet below sea-level.

The Burning Springs anticline in northwestern West Virginia, a prominent anticline that can be traced for a distance of 35 miles in a north and south direction, is an exception to the general northeast-southwest trend of the structural features. The Irvine-Paint Creek fault and anticline in eastern Kentucky is another. This is

an east-west trending anticline that is accompanied by normal faulting. It is an important "Corniferous" oil-producing structure.

The Pine Mountain thrust fault along the southeastern margin of the Appalachian basin constitutes a prominent structural feature in southeastern Kentucky and adjacent parts of Virginia. A rectangular block about 125 miles long and 25 to 30 miles wide is involved. Movement along the fault was dominantly in a northwest direction and nearly horizontal with a displacement of 2 miles at the northeast end and 10 miles at the southwest end.

Relation of Oil and Gas Accumulation to Structure

The occurrence of oil and gas in the majority of the pools in the Appalachian basin is controlled more by sand characteristics, which in the main were determined by the conditions under which the sands were deposited than by structural features later developed by earth movements. The pools occupy stratigraphic rather than structural traps. This is particularly true of the pools in Pennsylvanian, Mississippian, Upper Devonian, and Lower Silurian (Albion or Medina) strata. The producing sands occur as lenses embedded in less permeable shale or sandstone. Production is dependent on porosity which in turn is dependent on original conditions of accumulation of the sediment and their later cementation. Structural factors are secondary.

In contrast, the gas pools in fractured Onondaga chert and underlying Oriskany sandstone in southwestern Pennsylvania, western Maryland and northeastern West Virginia occupy structural traps consisting of elongated domes along the prominent anticlines that occur on the southeast limb of the Appalachian synclinorium. These domes are usually complexly faulted at the producing horizon.

The major Oriskany gas pools in south-central New York and north-central Pennsylvania also occupy domes along prominent anticlines. However, recent exploration in north-central Pennsylvania has indicated that the physical characteristics of the sandstone are as important as the structure. Several prominent domes have proved dry due to unfavorable sand conditions. The Oriskany sand gas pools of western West Virginia occupy stratigraphic traps.

Surface Indications of Oil and Gas

Oil seeps and gas springs occur at numerous and widely scattered localities throughout the Appalachian basin. Many of these were known to the Indians who obtained oil from them for medicinal purposes long before white men entered the region. The most famous is the oil spring which issues from the Cuba sandstone (Bradford First sand) of Upper Devonian age near Cuba, Allegany County, New York, mentioned by French Jesuit missionaries as early as 1656. The oil spring near Titusville, Pennsylvania, which led to the drilling of the Drake well, was visited by white men in 1748. Numerous oil seeps occur along the outcrop of the Le Beouf sandstone (Venango Third sand) of Upper Devonian age in Erie County in northwestern Pennsylvania. In quarries, this sandstone frequently contains oil residues. Hosmer Run in western Warren County, Pennsylvania, is the site of another oil spring, exploited by the Indians. Near McConnelsville, Morgan County, Ohio, oil seeps from the outcrops of the Saltsburg sandstone (First Cow Run sand) of Pennsylvanian age where small streams cross it.

Natural gas springs were observed by the early settlers of western New York along streams entering Lake Erie in the vicinity of Freedonia and Westfield. The gas issued from Upper Devonian shales. The "burning spring" along the Kanawha valley, nine miles east of Charleston, West Virginia , was visited by George Washington in 1775. The outflow of natural gas and salt water at this locality occurs where the Kanawha River crosses the Warfield anticline. Another famous "burning spring" is located on the north bank of the Little Kanawha River at the mouth of Burning Spring Run in Wirt County, West Virginia, along the axis of the Burning Springs anticline.

In Ritchie County, West Virginia, grahamite, a solid black brittle vein bitumen, was found in a vertical fissure, one to five feet wide at the surface and nearly a mile in length, which cut diagonally across the strike of strata of Upper Pennsylvanian and lower Permian age. A productive oil pool was developed on either side of the fissure at a depth of 1700 to 1800 feet. Apparently the grahamite represents an altered by-product of petroleum which escaped upward from the underlying oil sand. In northwestern Alabama the Hartselle sandstone and a bed of oolitic limestone near the base of the Gasper formation, both of Mississippian age, are locally impregnated with asphalt.

Distribution of Oil and Gas Fields

The oil and gas fields of the Appalachian province can be grouped into a number of sub-provinces on the basis of the geologic age of the producin formations. These overlap to a considerable extent as shown in Plate 1 At least twelve have made substantia contributions to the total oil and ga production of the province. They ar numbered consecutively on Plate 1 starting with the youngest.

PENNSYLVANIAN

The Pennsylvanian System in th Appalachian basin is divided into th Monongahela, Conemaugh, and Allegheny groups and the Pottsville Serie in descending order. The occurrenc of oil and gas in these strata is confined almost entirely to certain sandstone members. The Carrol sand which has yielded a little oil in Ritchi County in northwestern West Virginia, is the highest horizon fror which oil or gas in commercial quantities has been obtained in the basir This sandstone lies 260 feet above th base of the Monongahela group. Ga in commercial quantities has been obtained from the Pittsburgh coal at th base of the Monongahela group in th southwest corner of Pennsylvania an adjacent parts of West Virginia wher the coal is deeply buried.

Oil and gas production from Pennsylvanian strata in the Appalachia basin has been confined to southwestern Pennsylvania, southeastern Ohio northwestern West Virginia and eastern Kentucky. Oil and gas in commercial quantities have been obtaine from one sandstone and gas only fror another in the Monongahela group three sandstones have yielded oil an gas and three, gas only in the Conemaugh group; one sandstone ha yielded oil and gas and one, gas onl in the Allegheny group; and one, o and gas, and two, gas only in th Pottsville Series. The First Cow Ru sand of southeastern Ohio, occurrin near the middle of the Conemaug group, has been the most importan producer of oil in the Pennsylvanian The Big and Little Dunkard sand of southwestern Pennsylvania and adjacent West Virginia, at and near th base of the Conemaugh group, ar second in importance. The Salt sand of the Pottsville Series have made th largest contribution of gas. Some o has been obtained from these sand in eastern Kentucky.

The sandstones of the Pennsylvanian System are lenticular. The occurrence of gas and oil in them is confined to portions that possess the necessary porosity and permeability. Muc of the sandstone is too poorly sorted t constitute a good reservoir rock Where local structures in the form o minor folds are present, gas production is confined to the higher area

ıt may be limited to only parts of ıe structural high. Depositional con- tions were more important than ructural in determining the locations commercial deposits of gas and oil.

When compared with the deeper nds, those of the Pennsylvanian Sys- m have been of only minor import- ıce, but locally they have produced ınsiderable amounts of gas and some l. They are almost never the ob- ctives of a prospecting program to- ıy, but occasionally sufficient gas is ıcountered in one of these sands to arrant halting the drilling operation ıng enough to produce the gas if pipe ne facilities are available. This is ırticularly true of the Salt sands of ıe Pottsville.

MISSISSIPPIAN

Rocks of Mississippian age have een found productive of oil and gas ver a larger area in the Appalachian asin than those of any of the other eologic systems. The Mississippian ıb-province includes a large part of estern Pennsylvania, most of eastern)hio, all of western and southern Vest Virginia, eastern Kentucky, and art of southwestern Virginia. The il and gas are found mostly in sand- :ones but in parts of the sub-province limestone also serves as a reservoir ock.

The Mississippian System in the ıppalachian basin is usually divided ıto three groups, namely, in descend- ıg order, the Mauch Chunk, the Greenbrier, and the Pocono. The Mauch Chunk and Pocono consist al- ıost entirely of shales and sandstones, vhile the Greenbrier is mostly lime- tone. In the northern part of the sub- rovince only the Pocono is present. n the southern part in southern West /irginia and adjacent Virginia, the Maccrady shale comes in between the Greenbrier and the Pocono. Four andstones in the Mauch Chunk have ielded gas. Gas and occasionally oil ıave been encountered in several do- omitic and oolitic zones in the Green- rier. At least five sandstones in the Pocono have produced both oil and ;as.

Porous and permeable sandstones n the Mississippian capable of acting ıs reservoirs are lenticular. They vary ;reatly in persistence, texture, and hickness. Depositional conditions had ı greater influence than structural in letermining the places of accumula- ion of Mississippian oil and gas pools.

The Berea sandstone near the base of the Mississippian has its best de- velopment in the western and south- ern parts of the sub-province. It has been an outstanding source of both oil and gas in Ohio and West Virginia. Large volumes of gas have been obtained from the Murryville sand at the base of the Mississippian in western Pennsylvania in the northeastern part of the sub-province where the sand has its best development. The Murrysville sand occurs below the horizon of the Berea.

The Mississippian sands have been the source of large quantities of both oil and gas in the Appalachian basin. Southern West Virginia and adjacent areas in Virginia are the scene of greatest activity at present.

UPPER DEVONIAN SANDS SUB-PROVINCE

Sandstones in the Upper Devonian Series have been the source of the bulk of the oil produced in the Appalachian basin and have also contributed very substantial volumes of gas. All of the oil produced in New York has come from Upper Devonian sandstones. In Pennsylvania, these sandstones have accounted for the major part of the oil production and in West Virginia, a very substantial part.

The Upper Devonian oil and gas sands have their best development in western Pennsylvania where at least eighteen sandy zones occur that have proved productive over considerable areas. Some of these zones extend into the adjacent states of New York and West Virginia. A number of additional sandstones are important locally. The Bradford Third sand, the producing sand of the famous Bradford field, occurs in the Upper Devonian Series about 1800 feet below the top. The Richburg sand from which the major part of the New York oil production has come, occupies the same stratigraphic position.

The oil and gas pools of the Upper Devonian occupy stratigraphic traps. These consist of sand lenses embedded in shale or less permeable sandstone. Depositional conditions played a more important role than structural in determining the localization of pools. Structure did have an influence in bringing about the segregation of gas, oil, and salt water in the pools according to density but only to the extent that the physical nature of the reservoir rock permitted.

The oil pools of the Upper Devonian are confined largely to a belt comprising roughly the northwestern one-half of the sub-province. With a few exceptions, only gas pools occur in the southeastern one-half. The most plausible explanation for this distribution that has been advanced thus far is that the strata have been increasingly metamorphosed in a southeasterly direction, as witnessed by the increase in carbon ratios of the coals in that direction. The methane content of the natural gas increases in that direction also while that of the heavier hydrocarbons decreases. The oil and gas fields of the Mississippian sub-province exhibit a similar arrangement.

The northwestern limit of the Upper Devonian sands sub-province is determined by the thinning and replacement of the marine sandy facies that contains the oil and gas sands by a shaly facies in that direction. On the southeast side, the marine sandy facies passes into a continental "red bed" facies which, no doubt, is responsible for limiting production in that direction. However, the marine shaly facies which underlies the sandy facies in the oil and gas belt changes into a marine sandy facies in a southeasterly direction. (Bayles, 1949, p. 1703) Why the deeper sandstones have not proved productive thus far is still an enigma. Still deeper sands, such as the Oriskany, have produced natural gas in areas that have undergone corresponding degrees of metamorphism.

UPPER AND MIDDLE DEVONIAN "BROWN SHALE"

A black carbonaceous shale section ranging in age from Lower Mississippian to Middle Devonian has been a prolific source of natural gas in parts of eastern Kentucky and adjacent southwestern West Virginia. The shale, locally known as the "brown shale" ranges in thickness from 400 to 700 feet or more in the producing area. The entire thickness is usually shot. The reservoir is probably of the fracture type. Minor structural features present in the area do not seem to have had any influence on the accumulation. The fracture zones apparently are regional in character.

Gas in small quantities sufficient for local use only has been obtained from similar shales occupying approximately the same stratigraphic interval south of Lake Erie in northwestern Pennsylvania and adjacent Ohio.

Dundee Limestone

The major part of Ontario's oil production has come from a porous limestone formerly correlated with the Onondaga limestone of New York but now believed to be the equivalent of the Middle-Devonian Dundee limestone of Michigan. Although a considerable number of individual pools have been discovered, these have all been small. Only moderate quantities of oil have been recovered from them. Most of the Dundee limestone pools are located in the Chatham sag separating the Findlay and Algonquin

arches and, therefore, belong to the Cincinnati Arch oil and gas province.

Onondaga Chert and Oriskany Sandstone

Gas in commercial quantities has been encountered in either the Onondaga chert, the underlying Oriskany sandstone, or in both in the Allegheny Mountain belt of the Appalachian Plateau at seven localities in southwestern Pennsylvania, western Maryland, and northeastern West Virginia. The occurrences are confined to elongated domes along prominent anticlines that are complexly faulted at the producing horizon. In the area, the Onondaga formation of the Middle Devonian consists of a light to dark brownish gray chert, in part silty and mostly non-calcareous with considerable dark brownish-gray to black shale interbedded with the chert in the lower part. The Oriskany formation of the Lower Devonian is a calcareous sandstone. The reservoirs are of the fracture type. Three of the seven fields have produced substantial volumes of gas. Production from the other four has been small. The fields are in areas where the coals possess high carbon ratios. Some are very close to the southeastern edge of the Appalachian Plateau.

Oriskany Sandstone

The Oriskany formation of the Lower Devonian contains a quartzose sandstone member that has retained sufficient porosity to act as a reservoir rock over considerable parts of the Appalachian basin. As shown in Plate 1, the Oriskany outcrop can be traced from central New York around the northern, northeastern, and southeastern margins of the basin to southwestern Virginia. In the western part of the basin, the formation is cut out by the Devonian-Silurian unconformity before it outcrops. The formation is also absent in the extreme southwestern part of the basin.

The Oriskany sandstone has proved an important source of natural gas in two widely separated areas, namely, north-central Pennsylvania and adjacent parts of south-central New York and southwestern West Virginia. Southwestern West Virginia has been particularly outstanding. Here the productive area embraces nearly 200,000 acres. Substantial volumes of gas and some oil have also been obtained from the Oriskany sandstone in east-central Ohio. In addition, a number of Oriskany sand gas pools of lesser importance have been developed in eastern and northeastern Ohio and adjacent western and northwestern Pennsylvania.

In north-central Pennsylvania and south-central New York, the larger pools are restricted to prominent elongated domes along well-defined anticlinal trends. The structures are complexly faulted at the horizon of the Oriskany sandstone (Finn, 1949, pp. 320-334). Several small gas pools of the stratigraphic type occur in south-central New York where the sandstone pinches out to the north. All of the Oriskany sand gas pools of southwestern West Virginia are of the stratigraphic type. (McClain, 1949, p. 193) In the case of the rather widely scattered and, for the most part, small Oriskany sand pools of eastern Ohio and western Pennsylvania control has been partly stratigraphic and partly structural.

Salina-Guelph Dolomites

Dolomites in the lower part of the Salina formation and the upper part of the Guelph-Lockport formation of Silurian age constitute the most important gas-productive zone in southwestern Ontario. Some oil has also been obtained from this zone. Depositional conditions in conjunction with later folding and faulting controlled accumulation in the Salina dolomite, whereas accumulation in the Guelph-Lockport was due primarily to the presence of reefs (Roliff, 1949, p. 188).

The Newburg sand, a porous dolomite, that has yielded some gas in northeastern Ohio, occupies approximately the same stratigraphic position as the Salina-Guelph zone in southwestern Ontario.

"Corniferous" Limestone

The "Corniferous" limestone has been a major producer of oil in eastern Kentucky. Some gas has also been obtained from it. The term "Corniferous" was applied by the earlier geologists to the dolomite encountered beneath the Devonian black shale and above Silurian shales in wells in east-central Kentucky because it was thought that the dolomite was the equivalent of the Onondaga limestone of New York which, at one time, was called the Corniferous limestone. It has now been established on the basis of fossils obtained from cores that the major part of the dolomite known as the "Corniferous" in east-central Kentucky is Lockport (Middle Silurian) in age. (McFarland, 1938, pp. 1447-1451)

Porosity and permeability in the Lockport dolomite were developed by leaching during the interval of erosion represented by the Devonian-Silurian unconformity (Freeman, 1941, p. 187). A number of "Corniferous" pools in east central Kentucky encirc an area that appears to have been el vated as a low dome during midd Devonian time. Overlaying form tions were stripped by erosion expo ing the Lockport dolomite to leachin These leached dolomites after buri under Upper Devonian black sha and later sediments became the rese voir rocks of the "Corniferous" pool

Big Six Sandstone

The Big Six sandstone has been tl source of some gas in east-central Ke tucky. It occurs below the Lockpo dolomite and above Clinton shales an has been correlated with the Keef sandstone of central Pennsylvani northeastern West Virginia and wes ern Maryland (Young, 1949, pp. 3-56). The latter sandstone occurs nea the top of the Clinton group of th Middle Silurian.

The Big Six sandstone, where pre ent, consists of a fine-to mediu grained light gray quartzose san stone with conglomerate lenses. I ranges in thickness from 25 to 65 fee Accumulation of gas in the sandston has been controlled primarily by de ositional conditions and cementatio Structure has not been of primary im portance.

Irondequoit Dolomite

The Irondequoit dolomite of th Clinton group of the Middle Siluria has been an important producer o gas north of Lake Erie in souther Ontario, where locally it possesse sufficient porosity to act as a reservoi rock.

Albion (Medina) Sandstones

Sandstones of the Albion Serie have been an outstanding source o natural gas in western New York southern Ontario, and central Ohio In central Ohio, substantial volume of oil have also been obtained fro them. In New York these sands ar called Red Medina and White Med ina in descending order. In Ohio the are called Clinton due to an errone ous correlation made when gas wa first discovered in them. The Albio Series constitutes the lower divisio of the Silurian System in the Appalachian basin.

The important Albion pools occu in a broad arcuate belt which starts in Ontario County in west-central New York, extends west to the shores of Lake Erie taking in part of southern Ontario, and then swings southwest and in the form of a great arc continues underneath the lake to enter Ohio in the vicinity of Cleveland. From thence it continues across middle Ohio south to the Ohio River.

The deposition of the Albion Series ɩllowed the Taconian disturbance hich raised the land along the east-rn border of the Appalachian geo-ncline high above sea-level. Great luvial fan and flood plain deposits ere spread out over the Appalachian eosyncline along its eastern margin hich stood slightly above sea-level at ie time. The belt of Albion sand ɔols marks the approximate shore line here these continental sediments in-r-finger with the marine. In this elt the Albion represents a shore line eposit. Variations in porosity and ermeability, as well as lensing and iterial gradations, were the import-nt factors in the accumulation of the as and oil. These were determined by riginal conditions of sedimentation ıd later cementation of the sands. tructure played only a secondary ɔle in accumulation.

The productive belt is limited on ie north, northwest and west by the eathering out of the sands into shale nd limestone. On the south, south-ıst and east, the sands probably ac-umulated under continental condi-ons. Extensive prospecting south of ie main belt in New York and east of in Ohio has resulted only in the pening of a few scattered pools of elatively minor importance.

renton Limestone

The Trenton has been an import-nt source of both oil and gas along he Findlay arch which borders the ppalachian basin on the northwest. The oil has been produced chiefly rom the upper 50 feet of the Trenton nd commonly from the upper 25 feet, ut some has come from lower levels, 00 to 300 feet below the top of the imestone. The oil does not occur at ny definite horizon. Oil and gas ac-umulation in the Lima-Indiana field, vhich belongs to the Cincinnati Arch il and gas province, has been confined o areas where the limestone has un-lergone local dolomitization.

Six shallow gas pools have been pened in the Trenton limestone on he southwest side of the Adirondack Mountains at the east end of Lake Ontario in New York. Production has een small and the output has been onsumed locally. The limestone beds ıre not dolomitic and they do not ossess sufficient primary porosity to erve as reservoir rocks. The gas is ound in cavities, seams and joints in hale partings and shale beds and in he limestone itself. The gas does not ccur at any definite horizon. In a ingle well, gas may be found at as nany as twenty horizons distributed hroughout the entire thickness of the ormation. (Hartnagel, 1938, pp. 88-9).

Small quantities of oil have been obtained from Trenton limestone on the Powell Mountain anticline at Rose Hill in the southwest corner of Virginia. The occurrence reveals that locally the early Paleozoic rocks still retain some oil even in the closely folded Appalachian Mountains where they have undergone considerable deformation. The oil in the Trenton at Rose Hill does not occur in pore spaces inherent in the original rocks or in open spaces that have been induced by dolomitization. The oil is probably present in small fractures formed by the shattering of the rock during the period of folding and overthrusting. (Miller and Fuller, 1947). The oil is not confined to a single stratigraphic zone in the Trenton and wells only a few hundred feet apart produce from widely separted zones.

Small quantities of oil and gas have been recovered from the Trenton in south-central Kentucky and north-central Tennessee.

Considerable exploratory drilling has been conducted in the Trenton limestone in northwestern New York and central Ohio where the limestone is relatively shallow. Results have been disappointing. No areas of local dolomitization in the Trenton limestone, similar to the occurrence along the Findlay arch in northwestern Ohio and adjacent parts of Indiana, have been discovered. Where the Trenton rocks outcrop in central Pennsylvania in the closely folded Appalachian Mountains, there is no evidence of local dolomitization.

Sub-Trenton

A little oil and gas have been obtained from the Knox dolomite in north-central Tennessee and good shows of oil have been encountered in it at several localities in eastern Kentucky but no commercial production has been developed in it thus far in that state. "Knox dolomite" is a term applied to a thick succession of dolomitic rocks ranging in age from Lower Ordovician to Upper Cambrian, that occurs beneath the prominent unconformity at the base of the Middle Ordovician in the southern part of the Appalachian basin.

Sandy zones in a dolomitic succession of strata below the unconformity at the base of the Middle Ordovician in Ohio have yielded small amounts of oil at four localities. (Fettke, 1948, p. 1491). The zones in which the oil was encountered were at or near the unconformity and their porosity was probably related to it.

RECENT DEVELOPMENTS

Most of the drilling activity in the Appalachian basin in recent years has consisted of development work. This includes the drilling of inside locations, seeking extensions to known pools and deeper production from known sands in already producing areas, redrilling oil pools approaching exhaustion in connection with secondary-recovery operations, and drilling additional wells in exhausted gas pools that are being converted into storage pools.

Of the approximately 4700 development wells drilled in 1951, about 680 or 15 per cent were dry. Only 155 exploratory wells were completed, of which 107 or 69 per cent were dry. Exploratory wells represented only 3 per cent of the total number of wells drilled in 1951.

Pennsylvanian System. Almost no new drilling is undertaken at present that has the sands of the Pennsylvanian System as its sole objective. However, in spite of the great number of wells that have been drilled through the Pennsylvanian strata in the producing areas, occasionally sufficient gas is still encountered in one of the Pennsylvanian sands, particulary in the Pottsville Series, to make it profitable to produce the gas, if the well happens to be conveniently located with respect to a pipe line.

Mississippian System. The area in which the sands of the Mississippian System have proved productive was appreciably enlarged by an exploratory campaign that got underway in southern West Virginia in 1944. By 1948, eight separate gas fields had been discovered in Wyoming and McDowell Counties and adjacent sections of Raleigh, Boone, and Logan Counties. A proven reserve of about 200 billion cubic feet of gas on 71,000 acres had been established. (Tollefson, Mayfield, and McCamey, 1949, pp. 239-247) This has been considerably enlarged by later developments.

Gas in Mauch Chunk Group. The gas is found in four sandstones in the Mauch Chunk group, several dolomitic and oolitic zones in the Greenbrier limestone, and one sandstone, the Berea, near the base of the Pocono group. The Berea has been the most productive. The new fields are located in an area of high carbon ratios in the coals considerably south and east of the older Mississippian production, and nearer the southeastern edge of the Appalachian Plateau. The gas has a methane content in excess of 97 per cent. No oil has been found associated with it.

Southern West Viginia. The exploratory campaign which was started in southern West Virginia has now been extended into southwestern Vir-

ginia where a fair degree of success has already been attained. By the summer of 1952, four gas pools had been discovered in Buchanan County and one in Dickenson County.

The largest of the pools thus far discovered, the Kean Mountain in Buchanan County, includes an area of about seven square miles. Twelve gas wells and eleven dry holes have been completed in it. Three of the gas wells had initial open flow capacities ranging from 17,000,000 to 22,250,000 cubic feet of gas per day. The highest reservoir pressure recorded was 1480 pounds per square inch. The average depth of the wells is 2300 feet. The Greenbrier limestone is the main producing zone, but the largest well obtained its production in the higher Ravencliff sand.

Of the three smaller gas pools in Buchanan County, one has four producing wells and the other two have three each. The wells range in initial open flow capacity from 14,000 to 6,000,000 cubic feet per day. In addition to the above wells, two small isolated gas wells and 15 dry holes have been completed in the county.

The Nora pool in Dickenson County extends over about six square miles. Eighteen gas wells and one dry hole have been drilled in it. The gas wells range in initial open flow after acidization from 290,000 to 2,250,000 cubic feet per day. A reservoir pressure of 1200 pounds per square inch has been reported. Three small isolated gas wells and two dry holes have been completed in Dickenson County outside the Nora pool.

Wells are usually drilled through the Berea unless sufficient gas is encountered in one of the higher sands to make a commercial well. The only production from the Buchanan and Dickenson County pools up to the end of August 1952 has been gas used for drilling purposes. However, plans were underway at that time to construct a pipe line that would furnish an outlet for the gas. (Seifert, 1952.)

Upper Devonian. There has been no significant extension of the area in which Upper Devonian sands have been found productive in recent years. A great many wells have been drilled through the Upper Devonian Series in connection with exploration for Oriskany sand gas in south-central New York and north-central Pennsylvania. Although shows of gas have been encountered locally in Upper Devonian sands, no gas pool of significant size has been discovered in them thus far east of the Upper Devonian gas belt as previously defined. The wells were drilled with cable tools. It is not likely, therefore, that any important producing zone was overlooked. Recent prospecting for gas in the Upper Devonian in the Allegheny Mountains in southern Pennsylvania east of the gas belt likewise has been discouraging. Only insignificant volumes of gas have been encountered in the Upper Devonian sands.

Within the Upper Devonian subprovince, as outlined in Plate 1, extensions of old pools, as well as new gas and oil pools of small size but of significance to the operators concerned, are still being discovered in spite of the very considerable number of wells that have already been drilled in the area. Occasionally a pool of more than local interest is found. The Music Mountain oil pool discovered late in 1937 is an example. The pool is located at the southwest edge of the Bradford pool in the area between the two lobes into which the latter pool is divided at its southwest end. It had produced nearly 5 million barrels of oil at the end of June 1952 from an area of 670 acres. The reservoir rock is a shoe-string type sand body, 4 miles long and only 800 to 2000 feet wide that occurs about 200 feet above the Bradford Third sand, the producing sand of the Bradford pool. Every well drilled to test the Bradford Third sand in the vicinity passed through the horizon of the producing sand of the Music Mountain pool, yet this rich little oil pool remained undiscovered for a period of 66 years after the discovery of the Bradford pool.

The Haskill sand gas pool which underlies the Guffey oil pool south of Bradford is another example of a relatively recent discovery in the Bradford district. The Guffey oil pool produces from the Bradford Third sand. A well drilled in 1943 to the Haskill sand, which lies about 450 feet below the Bradford Third, encountered gas in the deeper sand. This led to the development of a gas pool of about 6000 acres in the area from which approximately 4 billion cubic feet of gas have been obtained.

Upper & Middle Devonian. The Upper and Middle Devonian "brown shale" has been the major source of the gas produced in eastern Kentucky in recent years, about 58 billion cubic feet in 1951 or 80 per cent. (Wood and McCarville, 1952, p. 1073) Most of the present activity in the "brown shale" sub-province consists in drilling development wells.

Maryland Gas. Maryland became a gas producing state in 1949 with the discovery of the Mountain Lake Park field along the Deer Park anticline in the western part of the state. The gas is obtained from fractured Onondaga chert and underlying Oriskany sandstone. It is estimated that the total production to March 1, 1952 was 4.5 billion cubic feet and that the reserve was between 15 and 20 billion cubic feet. (Richards, 1952, p. 1238) The Mountain Lake Park field is the latest field to be developed in the Allegheny Mountain area.

New York & Pennsylvania Gas. The exploitation of the gas resources of the Oriskany sandstone in south-central New York and north-central Pennsylvania started in 1930 and in southwestern West Virginia in 1934. These are the two areas from which the major part of the Oriskany production has come.

By 1946, interest in the northern area had waned. Several years had elapsed without any significant new discovery and the developed fields were approaching exhaustion. However, the Marshlands anticline, the next anticline southeast of the Sabinsville, along which two major Oriskany sand pools were located, had had four small Oriskany wells completed along it between 1933 and 1942, whose production held up remarkably well. Drilling, therefore, was resumed on this structure in 1947. This led to the development of the East Fork-Wharton pool, the first major Oriskany sand pool to be opened on the southeast side of a large area in which no sandstone occurs at the Oriskany horizon. This focused attention on the wide belt which had not been tested between the area in which the sand is absent on the northwest side and the outcrop of the sandstone on the southeast side.

The discovery of the Leidy field on the next anticline to the southeast followed early in 1950. By the end of 1951, 63 producing wells had been drilled in this pool with initial open flow capacities ranging from 400,000 to 145,000,000 cubic feet per day, the average being 11,000,000 cubic feet. The H. E. Finnefrock No. 1 well of the New York State Natural Gas Corporation, completed on February 2, 1951, with an initial open flow capacity estimated at 145,000,000 cubic feet of gas per day, is the largest gas well ever drilled in the Appalachian basin. By the end of 1951, this well had produced nearly 19½ billion cubic feet of gas and was still producing at the rate of 25,000,000 cubic feet per day. The initial reservoir pressure of the Leidy field was 4,200 pounds per square inch, which is abnormally high for a depth of 6000 feet. At the end of 1951, the developed area included 8,400 acres. This

has been increased somewhat since. Production during 1951 was at the rate of about 150,000,000 cubic feet per day. The life of the field will be relatively short on account of the intensive competitive exploitation that it has undergone. The total reservoir content is estimated at between 75 and 100 billion cubic feet.

The Driftwood pool, southwest of the Leidy and East Fork-Wharton pools, was discovered in 1951. It is undergoing intensive development at the present time.

The recent developments have attracted a great deal of risk capital from outside the gas industry and a boom of considerable magnitude has been underway in north-central Pennsylvania during the past two years. A number of structures in the general area have been tested with negative results due to unfavorable sand conditions. Others are in the process of being tested at present.

Southeastern Ohio. Another area whose Oriskany possibilities attracted attention in 1952 includes a belt about 30 miles long and 6 miles wide in southeastern Ohio, north of and along a continuation of the trend of the productive belt in southwestern West Virginia. Several widely scattered wells have encountered commercial production in the Oriskany in the area.

In Ontario, the Salina-Guelph in the area of the Chatham sag has been the objective of the major part of the exploratory drilling in recent years, whereas most of the development wells have been drilled in the area of the Irondequoit-Albion gas fields in southern Ontario. (Roliff, 1952, pp. 1252-1257.)

There has been no significant discovery in the Albion (Medina) zone outside the boundaries of the area outlined in Plate 1, in recent years, although a number of exploratory wells are drilled each year in the territory to the south and east with this zone as their objective. Most of the wells drilled inside the sub-province are development wells, either inside locations or step-outs seeking extensions to producing areas. However, areas still remain undrilled inside the sub-province that warrant exploratory tests. Such tests still uncover new pools, usually small but nevertheless profitable to the operators. The Canton gas pool in northeastern Ohio, opened in 1945, was the last major discovery. It proved productive over an area of 16,640 acres and had produced nearly 65 billion cubic feet of gas by the end of 1951. Producing wells had been drilled both north and west and south and west of the area in which the pool was discovered. A well with a good show of gas that was abandoned as a dry hole in the southern part of the undrilled embayment discouraged further drilling for a period of 12 years. (Belden, 1952, pp. 59-70.)

Oriskany Sand, Gas Developments. Oriskany sand gas developments in north-central Pennsylvania; Onondaga chert and Oriskany sandstone gas production in the Allegheny Mountains of southwestern Pennsylvania, eastern West Virginia and western Maryland; and Mississippian gas developments in southern West Virginia and southwestern Virginia; have extended gas production almost to the edge of the Appalachian Plateau. These developments have shown that commercial deposits of natural gas can and do occur in areas where the carbon ratios in the coals are high, well over 70 per cent. This has necessitated some revision of ideas in regard to the potentialities of the closely folded Appalachian Mountain area east of the plateau. Until recently, this area had practically been written off as a possible oil and gas province.

Gas in Virginia. Gas was discovered in commercial quantities in the Early Grove field on a minor fold in the center of a broad belt of Mississippian rocks in the closely folded Appalachians in Scott and Washington Counties in southwestern Virginia in 1931. The gas occurs in sandy lenses in the Cove Creek limestone which overlies the Maccrady shale in the area. Porosity and permeability in the reservoir rock are very low. Six producing wells have been drilled. They produced 18,812,000 cubic feet of gas during the first one-half of 1952, as compared with 52,706,000 cubic feet during the first one-half of 1940, the peak period. (Averitt, 1941; Seifert, 1952.)

A well drilled in the closely folded Appalachian in Rockingham County in western Virginia in 1941 encountered an initial open flow of 100,000 cubic feet of gas per day, with a reservoir pressure of 1,150 pounds per square inch, in the Oriskany sandstone. The well is located about four miles from the nearest Oriskany outcrop. (Price and Tucker, 1949, pp. 62-63.) A second well drilled in the same vicinity in 1951 had an initial open flow capacity of 1,043,000 cubic feet; a third, 286,000 cubic feet after it was shot; and a fourth resulted in a dry hole.

Oil in commercial quantities was discovered in the Trenton limestone on the Powell Valley anticline at Rose Hill in the southwest corner of Virginia in 1942. The Rose Hill [illegible] located in a window in the Pine Mountain thrust fault block. The oil does not occur in primary pores [illegible] open spaces that have been [illegible] the limestone by dolomitization, [illegible] is probably present in small fractures formed by the shattering of the rock during the period of folding and overthrusting. The oil is not confined to a single stratigraphic zone in the Trenton. Wells only a few hundred feet apart produce from widely separated zones. (Miller and Fuller, 1947.) At the end of 1946, there were 15 wells in the field producing approximately 400 barrels of oil per day. At the end of 1947, production had dropped to 82 barrels and by 1952 to about 30 barrels from 12 wells. The oil in the Rose Hill field is a Pennsylvania Grade crude.

Pennsylvania Gas. An Ordovician test on the Schellsburg dome in Bedford County in south-central Pennsylvania was completed in the Bellefonte dolomite (Lower Ordovician) early in 1952 at a depth of 8,979 feet. A flow of 600,000 cubic feet of gas per day was encountered at 8,870 feet in the dolomite a short distance below its top, but the flow exhausted itself during the period that the well was being drilled deeper.

A Cambro-Ordovician test was abandoned early in 1951 on the Nippenose dome in Lycoming County, Pennsylvania, a typical elongate structure in the closely folded Appalachians of central Pennsylvania. The well started near the top of the Bellefonte dolomite (Lower Ordovician) and was bottomed in the Warrior limestone (basal Upper Cambrian) at a depth of 5808 feet. A small show of gas was reported in the Gatesburg formation of the Upper Cambrian. Acidizing did not increase the flow.

Exploratory Wells New York. An exploratory well in northeastern Chenango County in east-central New York was drilled to Pre-Cambrian granite in 1949. The well started in Hamilton shales (Middle Devonian) and had a total depth of 5701 feet. Copious quantities of brackish water were encountered in Lower Ordovician and Upper Cambrian dolomites at several horizons, indicating the existence of some porosity and permeability in the dolomites and also suggesting that dilution of their connate water by fresh water had occurred at some stage in their history. A Cambro-Ordovician test in south-central New York, the E. C. Kesselring No. 1 of the New York State Natural Gas Corporation, in the northeast corner of Chemung County, is now drilling at a depth of 10,756

feet. This is the greatest depth that has been reached thus far with cable tools. The well started in Upper Devonian shale and is now drilling in an Upper Cambrian sandy dolomite.

The Arthur Bennett No. 1 well of The California Company, completed in 1951 at a depth of 12,343 feet, is the deepest well in the Appalachian basin at present. It was drilled with rotary tools. The well is located on the anticline that bounds the Bernice semi-anthracite coal basin of Sullivan County in northeastern Pennsylvania on the southeast side. The well started in the Catskill facies of the Upper Devonian and was bottomed in Upper Ordovician shales. It proved dry in all formations.

Exploratory drilling during the past two decades has met with a considerable degree of success in adding to the natural gas reserves of the Appalachian province. This has not been true of oil. During that time there were no new discoveries of oil comparable to those of gas in the Oriskany sand fields of New York, Pennsylvania and West Virginia; or in the "brown shale" in eastern Kentucky and southwestern West Virginia; or in the Mississippian sandstones and limestones in southern West Virginia and adjacent Virginia. The Music Mountain pool in northwestern Pennsylvania, discovered in 1937, was the only oil pool of note to be developed and it has produced only 5 million barrels of oil.

SECONDARY RECOVERY OF OIL

The oil industry in the Appalachian province has been able to maintain its present position only through the application of secondary-recovery methods to oil pools that had already reached or were approaching their economic limit by primary-production methods.

Air and gas injection of the intensive type commenced to be employed in southeastern Ohio and western Pennsylvania on a small scale as early as 1911 and 1916. Water flooding on a noticeable scale dates back to 1920 in New York and northwestern Pennsylvania.

Today practically all of the oil produced in New York comes from water-flooding operations. The Bradford field accounts for 80 per cent of Pennsylvania's production. All of this is recovered through water flooding. about one-half of the remainder of the State's output is obtained from air- and gas-repressuring projects. In West Virginia, gas drives produced 22.3 per cent of the State's total oil production in 1950 and water flooding, 20.4 per cent. Air and gas drives have been used extensively in Ohio in the past and to a lesser extent in Kentucky. Water flooding has been underway in one pool in Ohio since 1939 and has recently been introduced in two pools in eastern Kentucky.

About 42 per cent of the annual oil production of the Appalachian province at present comes from the Bradford field of Pennsylvania and New York. This field was discovered in 1871. It had produced a little over 500,000,000 barrels of oil from approximately 85,000 acres at the end of 1951. Of this, over 285,000,000 barrels were recovered through water flooding.

FUTURE POTENTIALITIES

The area underlain by Pennsylvanian strata in the Appalachian basin has been fairly thoroughly explored. It is not likely that any significant additions to reserves of either gas or oil will be discovered in Pennsylvanian rocks.

Recent developments in southern West Virginia and southwestern Virginia indicate that the area in which commercial gas pools occur in Mississippian sandstones and limestones may be extended still further in this part of the Appalachian basin. Mississippian formations also offer some possibilities in the Cumberland Plateau region of Tennessee and in northwestern Alabama and northeastern Mississippi.

The area of production from Upper Devonian sandstones will probably not be greatly enlarged in the future. However, in spite of the great number of wells that have already been drilled in the sub-province, there is still room for the occasional discovery of a new small gas or oil pool, particularly gas.

A number of prominent domes along anticlinal axes in the Allegheny Mountain belt in southwestern Pennsylvania and eastern West Virginia have not been adequately tested in the Onondaga chert and underlying Oriskany sandstone. It is highly probable that some additional gas fields of the fracture type will be discovered.

Several structures still remain untested in the north-central Pennsylvania Oriskany gas territory. In addition, there still are large areas in eastern Ohio and western Pennsylvania in which the Oriskany sandstone possibilities have not been adequately explored. There probably has been sufficient drilling to indicate that fields comparable in size to those of southwestern West Virginia do not exist, but there is ample opportunity to discover additional moderate-sized pools similar to the ones already developed.

A considerable reserve of natural gas and possibly some oil exists in the Albion (Medina) sandstones under the waters of Lake Erie. Lake Erie is sufficiently shallow to make it feasible at some future time to exploit at least part of this reserve. (Cathcart and Fettke, 1949, pp. 4-5.)

The largest area in the Appalachian basin in which almost no commercial gas or oil production has as yet been developed occurs in northeastern Pennsylvania and adjacent central New York. (See Plate 1.) A few scattered small gas fields in Trenton limestone have been developed along its northern margin. With the exception of the borders, only a little exploratory drilling has been conducted in the area. A well, recently completed in Pre-Cambrian granite in the northeastern part, encountered considerable quantities of brackish water at several horizons in Cambro-Ordovician dolomites indicating some porosity and permeability in these beds. Not much is known in regard to the subsurface stratigraphy and structure. (Willard and Stevenson, 1950, pp. 2269-2283.) Lines of equal carbon ratios projected across the area from the coal fields at the southwest end are high. However, in view of recent developments elsewhere in the basin, it would seem that this northeastern area is worthy of further investigation.

The development of a small gas and a small oil pool in southwestern Virginia in the closely folded Appalachians and the recent discovery of what may prove to be a commercial gas pool in the Oriskany sandstone in western Virginia, indicates that the western margin of this belt may possess some potentialities as a future source of gas, if not oil.

Ordovician and Cambrian strata underlie the entire Appalachian basin. They have yielded a little oil and a small amount of gas in the basin. Although the quantities have been almost negligible, the occurrences have demonstrated that the rocks do contain oil and gas in places. Inasmuch as only a small part of the area can be considered to be adequately tested, it seems possible that there are areas where conditions existed in these rocks that were favorable for the accumulation of larger deposits. The Ordovician and Cambrian rocks of the Appalachian basin still offer posibilities of major discoveries.

The gray Oswego sandstone at the base of the thick continental red-bed succession that constitutes the uppermost division of the Cincinnatian Series (Upper Ordovician) in the northeastern part of the Appalachian basin is perhaps the highest zone in

hich gas or oil may be expected. The ndstone may possess sufficient poros- y and permeability to act as a reser- oir rock in places where depositional nditions were favorable, such as ong an ancient shoreline. The re- lts obtained in the limited number wells that have been drilled through is zone have not been encouraging.

Middle Ordovician limestones, in- uding the Trenton and the Black iver, underlie the entire basin. Ex- oratory tests of the Trenton lime- one in northwestern New York and ntral Ohio, where it occurs at rela- vely shallow depths, as yet have been sappointing. No dolomitization of e limestone similar to that with hich the oil and gas occurrences ong the Findlay arch are associated ave been discovered. Also there is o evidence of local dolomitization here the limestone crops out in the osely folded Appalachians. There is possibility, however, that the Tren- on limestone may have undergone ufficient fracturing along the crests f some of the stronger anticlines in e eastern part of the basin to act as reservoir rock. The Rose Hill field n southwestern Virginia possesses this ype of reservoir in the Trenton. The eep test recently completed on the chellsburg dome, a prominent struc- ure in south-central Pennsylvania, ncountered no evidence for the exist- nce of porosity or permeability, either rimary or secondary, in the Trenton nd Black River limestones.

The Lower Ordovician and Upper Cambrian dolomites, particularly cer- ain sandy zones in the latter, prob- bly offer better possibilities for the ccurrence of gas and oil than do the Middle Ordovician limestones. The rominent unconformity between the Middle Ordovician and the Lower Ordovician Series could have played n important role in the localization f any such occurrences. (Fettke, 948, pp. 1491-1492.)

A number of strategically located tratigraphic tests will be required to valuate the possibilities of the Tren- on and sub-Trenton rocks. Their great depth under much of the basin will make their exploration very ex- pensive.

In conclusion, it is believed that a sufficient number of undiscovered gas pools remain in Middle and Upper Paleozoic strata in the Appalachian basin to make a substantial addition to the total reserves. With respect to oil, the situation does not appear as fa- vorable. The bulk of the oil reserve in strata younger than Ordovician probably occurs in the oil pools that have already been discovered. It is the oil that was not obtained by the old production methods but which can now be recovered by the newer techniques that have been developed in connection with secondary-recovery operations. There are still many oil pools remaining in which secondary- recovery methods either have not been applied at all or have been applied only on a small scale.

The potentialities of the Ordovician and Cambrian strata under most of the Appalachian basin are still an un- known quantity.

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